Additive Manufacturing at NASA: Qualification and Certification

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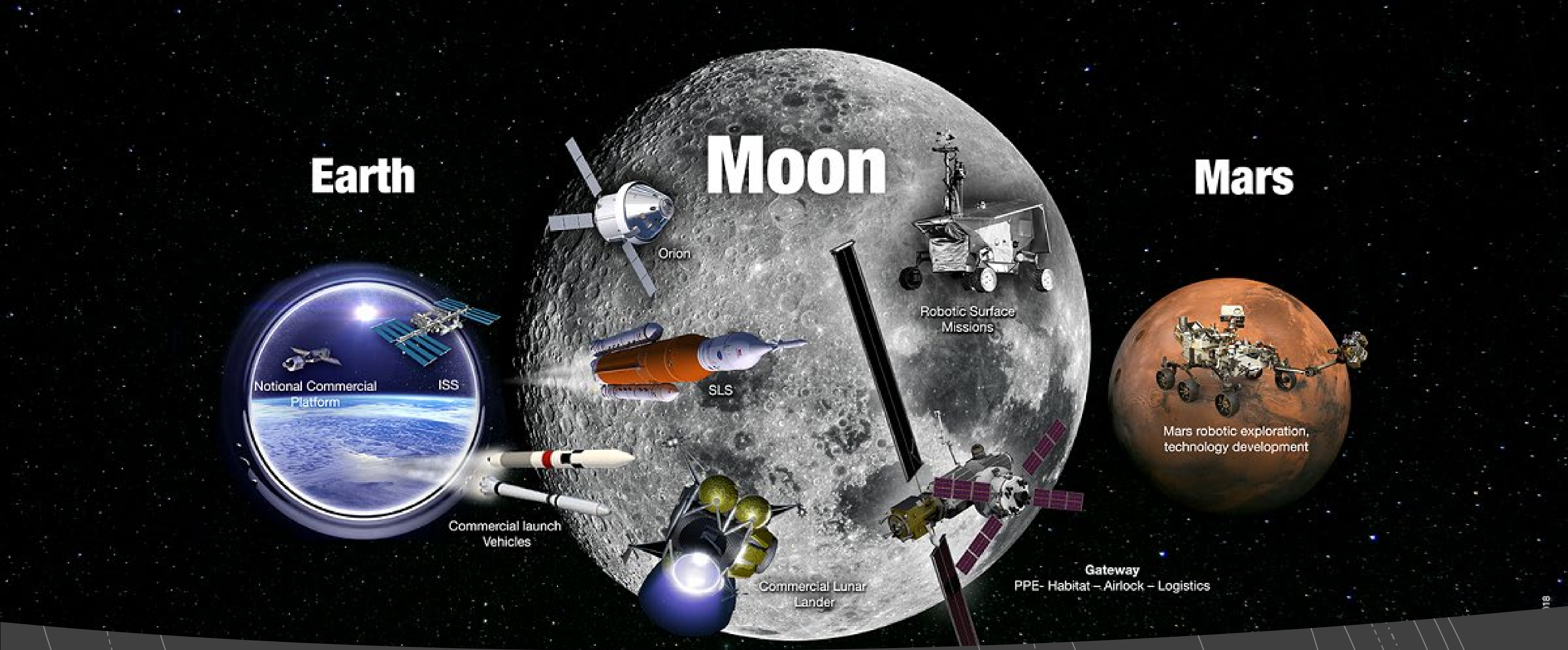
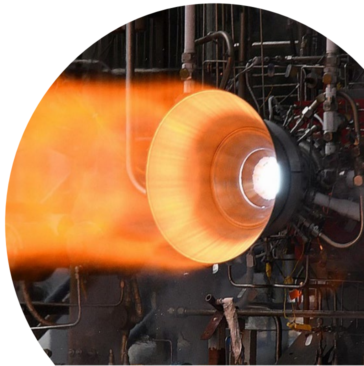


Exciting time at NASA with a lot of activities around Earth Orbit, getting ready to go to the Moon with eyes on Mars

Additive Manufacturing at NASA

- **NASA fully embraces advantages of AM**
  - New design and performance opportunities
  - Decreased part count
  - Shorter design-fail-fix cycle time
  - Shorter lead times and lower costs (when compared to many legacy technologies)
- But we **understand the challenges**, especially in delivering high value-for-performance AM hardware
- **NASA has a dual role**
  - Drive and foster **AM Technology Research and Development** in support of broad industry adoption and industrialization (Paul Gradl's Presentation)
  - **Spaceflight hardware certification** to assure AM hardware for access to space can safely meet mission objectives --> today's presentation
- Today's talk will overview NASA's **AM Design and Hardware Qualification and Certification approach,** including a snapshot summary of **NASA Tech Standard 6030**



Spaceflight AM Hardware Certification

- The commercial space industry is charging ahead with the development and use of additively manufactured components for spaceflight applications—whether NASA is ready or not
- NASA purchases technologies and capabilities (e.g., launch services) and has the responsibility to certify that they meet its requirements
- NASA also needs to ensure its engineers can properly design, manufacture, and integrate its own AM parts
- NASA and the Commercial Space Industry needs to have a clear set of common practices for AM
  - Standardize approaches for design, manufacturing, and verification
  - Maximize interoperability
  - Help direct innovation without stifling it

Technical Standards at NASA

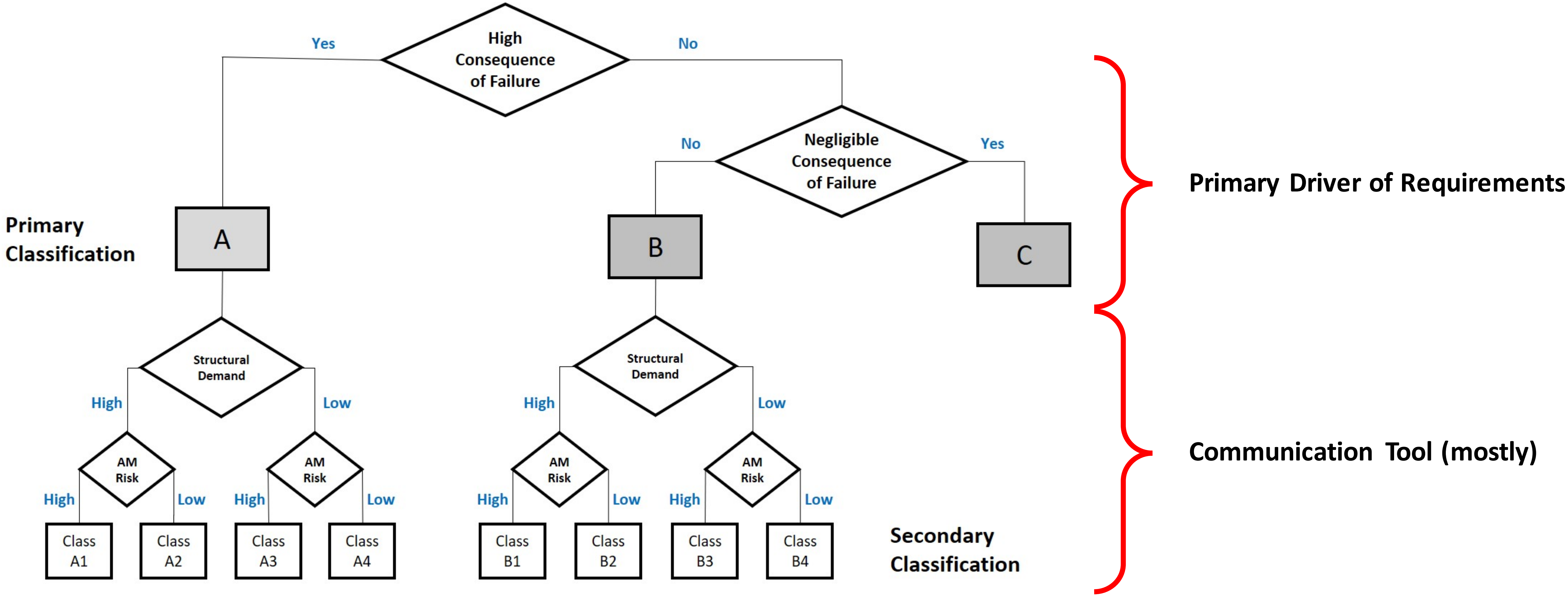
- As of 2015, there were no comprehensive consensus industry-standards for AM
- In order to effectively utilize AM technologies in its designs and systems, NASA released its own Technical Standards for AM (focused for Spaceflight Systems) in April of 2021
  - NASA-STD-6030, *Additive Manufacturing Requirements for Spaceflight Systems*
  - NASA-STD-6033, *Additive Manufacturing Requirements for Equipment and Facilities Control*
- Set a uniform framework for AM qualification and certification methodologies
- Currently being cited in human spaceflight programs

AM Standard 6030 – Applicability

Category	Technology	Materials Form	Class		
			A	B	C
Metals	L-PBF	Metal Powder	X	X	X
	DED	Metal Wire	X	X	X
	DED	Metal Blown Powder	X	X	X
Polymers	L-PBF	Thermoplastic Powder		X	X
	Vat Photopolymerization	Photopolymeric Thermoset Resin			X
	Material Extrusion	Thermoplastic filament			X

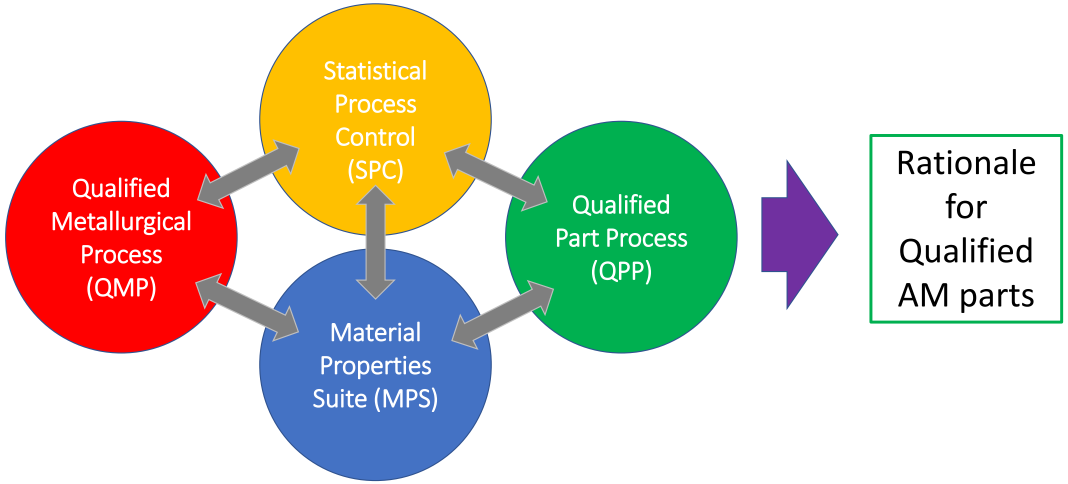
- Use of technologies and materials not explicitly described in Table 1 requires approval by the cognizant engineering organization and the responsible NASA Materials and Processes (M&P) organization
- Adaptive technologies, where the heat input can change during the manufacturing process, are not allowed
  - e.g. Electron beam powder bed fusion (E-PBF)

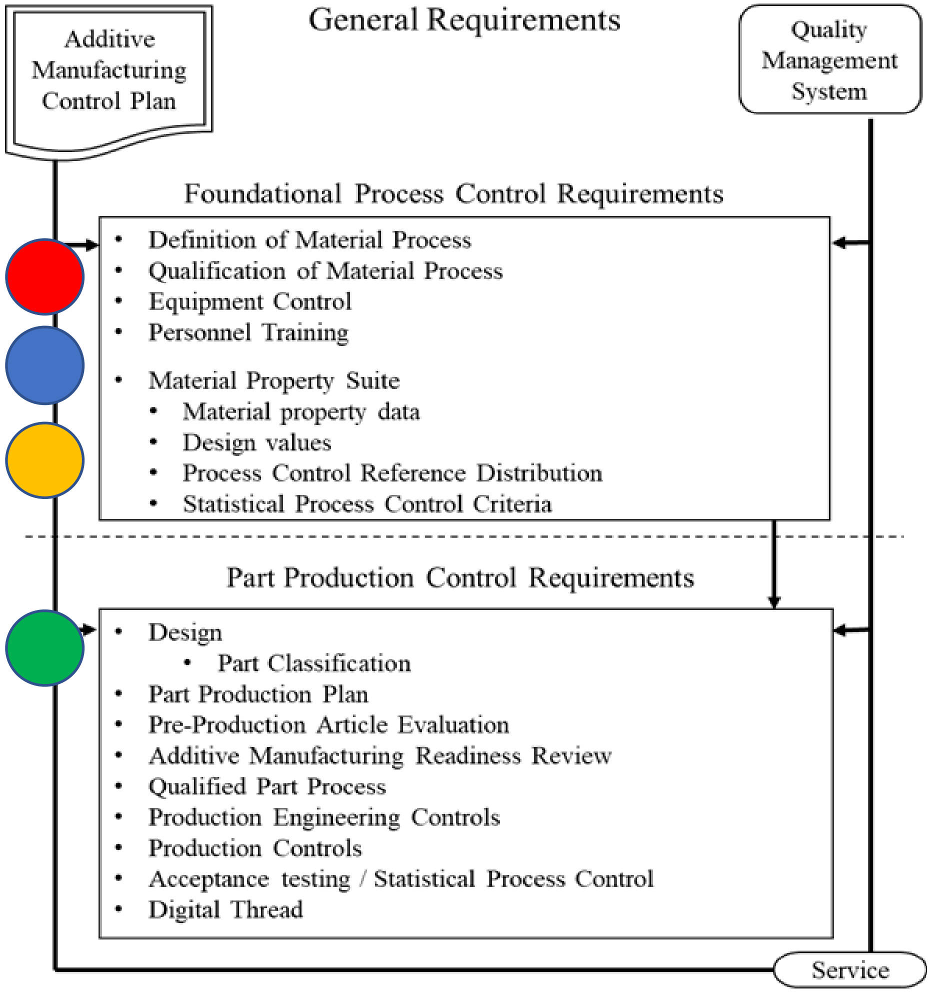
AM Standard 6030 - Classification



Summary of Methodology

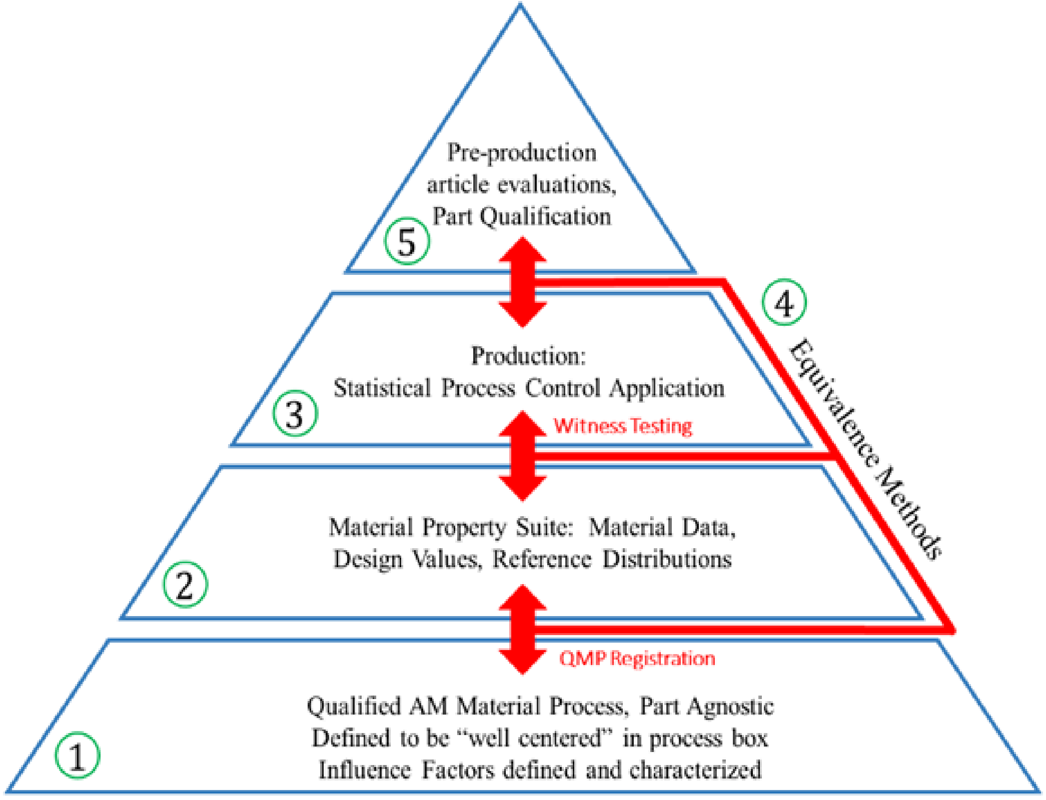
- General Requirements
  - Additive Manufacturing Control Plan (AMCP) and Quality Management System (QMS)
  - Backbone that defines and guides the engineering and production practices
- Foundational Process Control Requirements
  - Includes the requirements for AM processes that provide the basis for reliable part design and production
- Part Production Control Requirements
  - Includes design, assessment controls, plans (PPP), preproduction articles and AM production controls





Qualified Material Process (QMP)

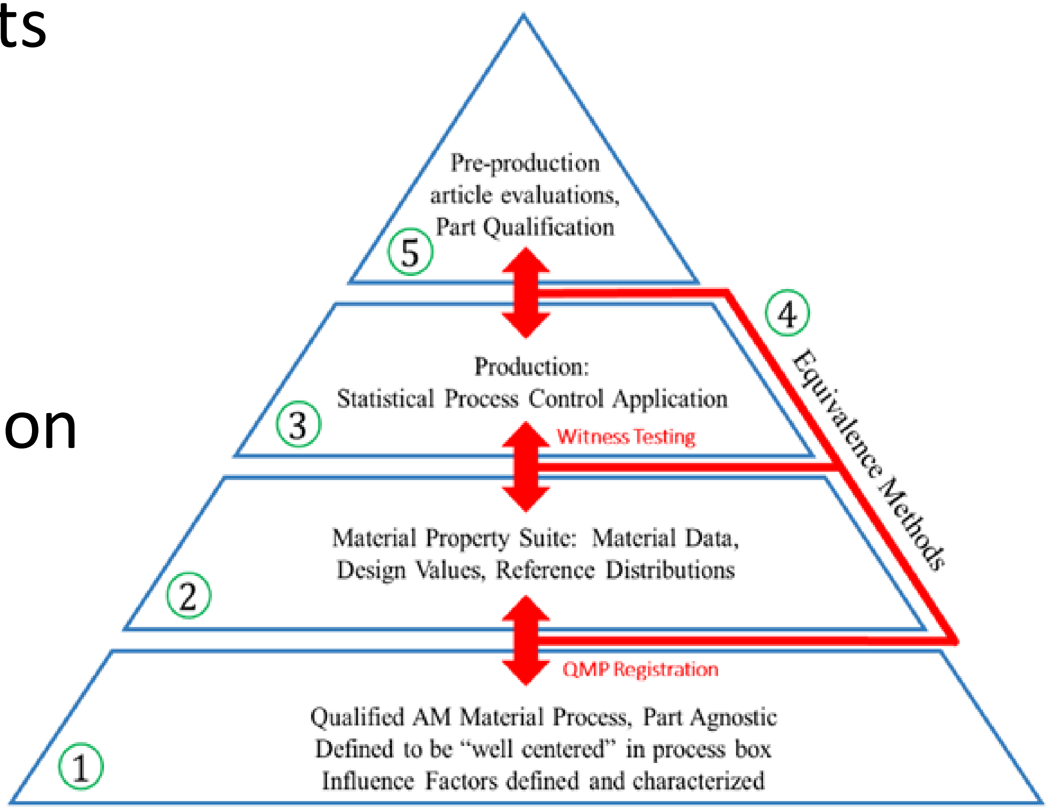
- Begins as a <u>Candidate</u> QMP
- Defines aspects of the basic, <u>*part agnostic*</u>, fixed AM process:
  - Feedstock Controls
    - What the raw material inputs are
  - Fusion Process
    - How a machine operates
  - Post Processing Process (e.g., heat treatment)
    - Controls material evoluation and end state
- Qualification of the Candidate Material Process
  - Establishes a QMP: Qualified Material Process
  - Requirements vary based on classification
- Enabling Concept
  - Machine qualification and re-qualification, *monitored by…*
  - Process control metrics, SPC, *all feeding into…*
  - Design values



Material Property Suite (MPS)

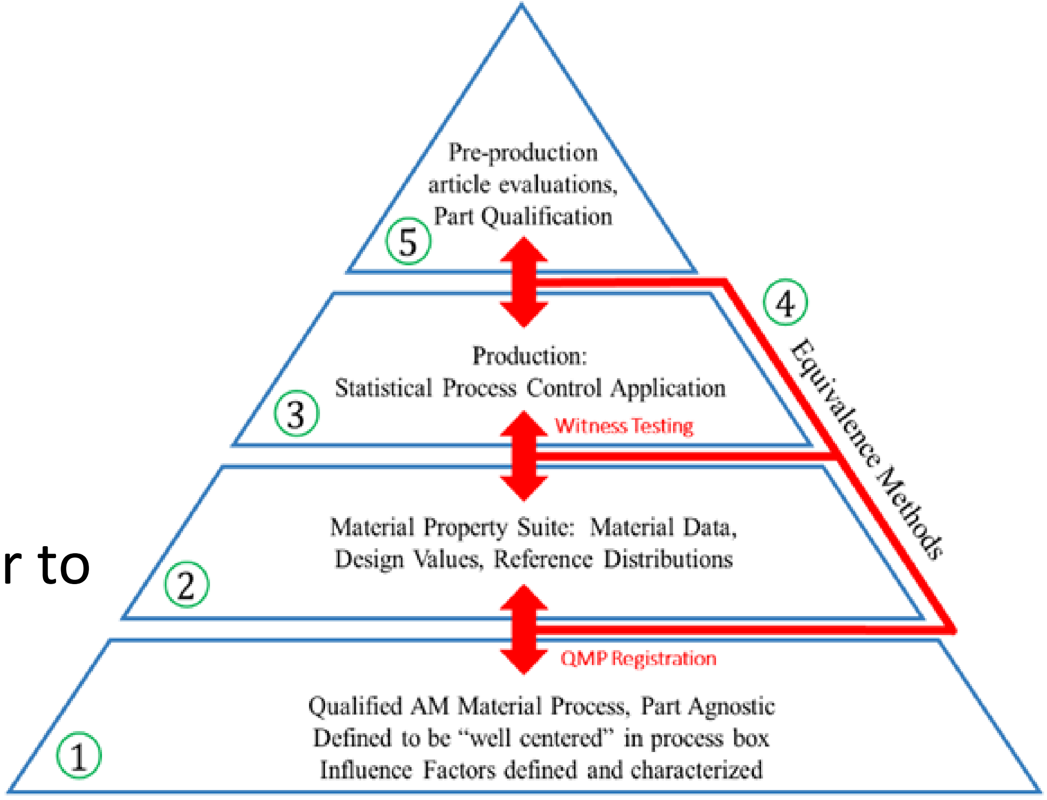
The Material Property Suite (MPS) consists of four inter-related entities:

1. Data Repository
2. Design Values
3. Process Control Reference Distribution (PCRD)
4. SPC acceptance criteria for witness testing



Statistic Process Control (SPC)

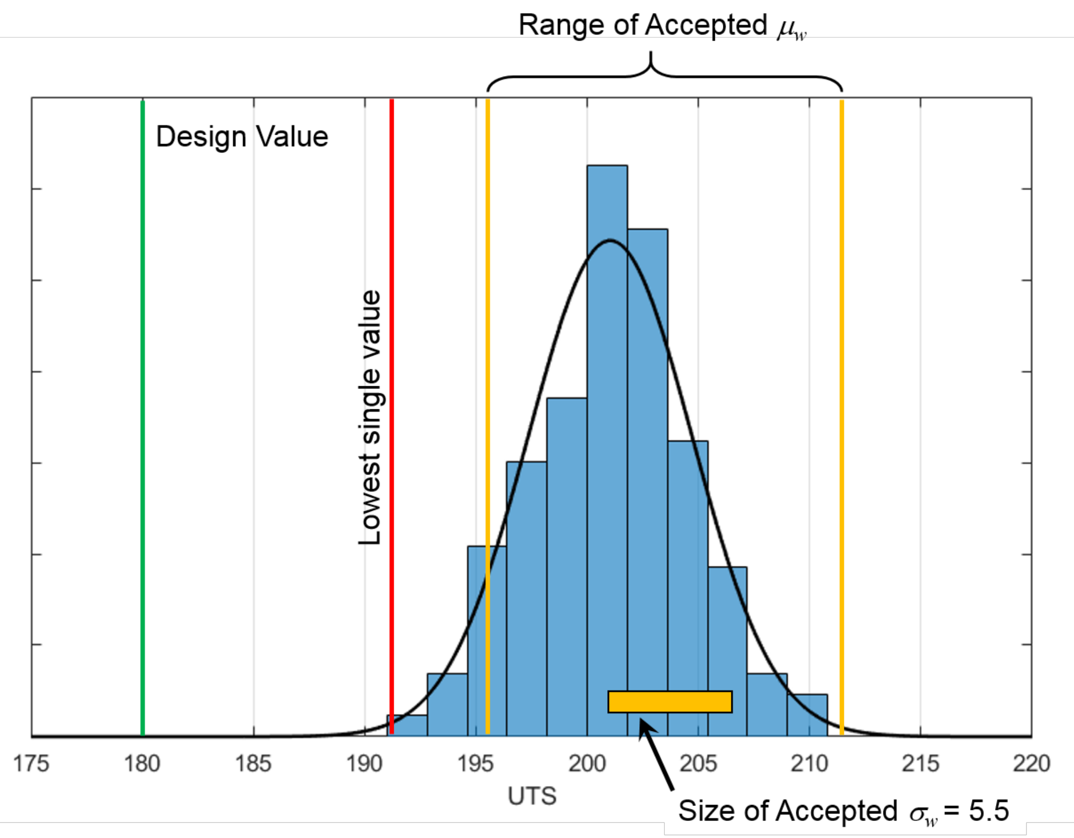
- *Statistical equivalency evaluations* substantiate design values and process stability build-to-build
  a) Process qualification
  b) Witness testing
  c) Integration to existing material data sets
  d) Pre-production article evaluations
- Equivalency of material performance is an anchor to the structural integrity rationale for additively manufactured parts



The dark and scary place most manufacturers are NOT used to operating….

Material Properties Suite – PCRD and SPC Criteria

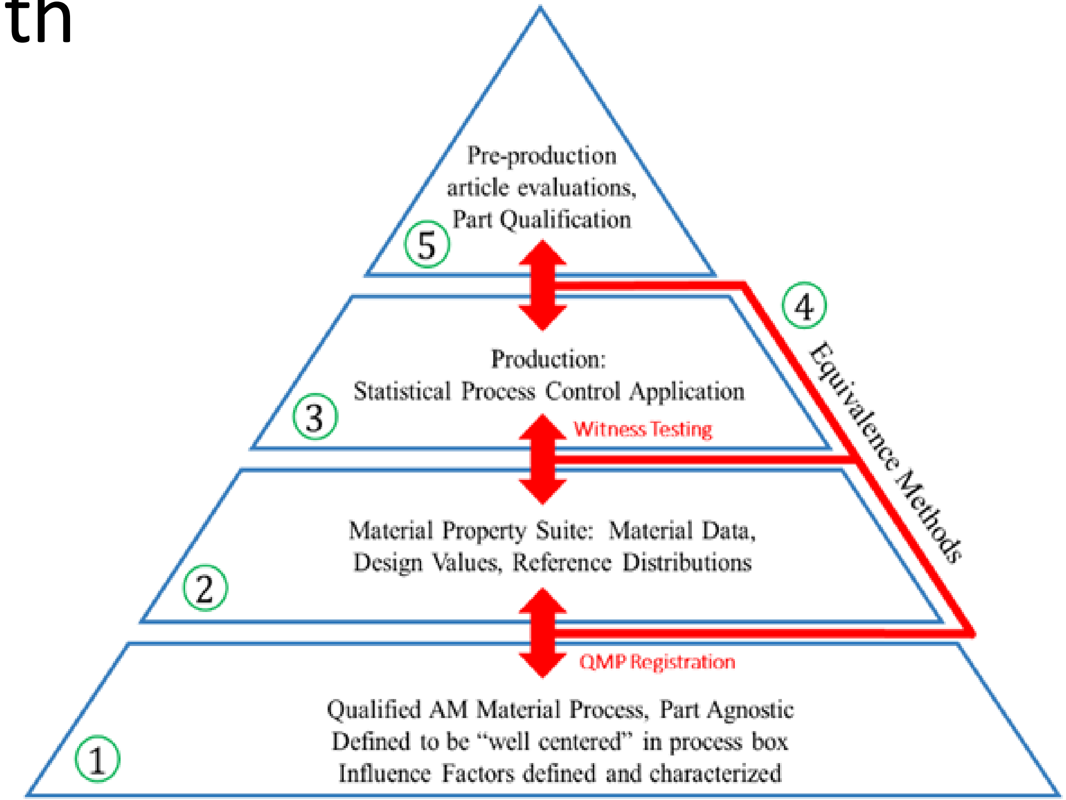
- Witness test acceptance is **not** intended to be based upon design values or "spec mins"
- *Part* acceptance is based on witness tests reflecting properties in the MPS used to develop the design values
- Suggested approach
  - Acceptance range on mean value
  - Acceptance range on variability (e.g., standard deviation)
  - Limit on lowest single value



Foundation Complete!!

A basis to begin designing AM parts with certification intent is feasible once the foundation is laid.

Foundation is now ready to support AM part development in an environment with suitable rigor to establish certification.



AM Part Production

1. Follow the plan, *always,* with no short-cuts
2. Do not change a Qualified Part Process without re-qualification
3. Efficiency in process monitoring is critical to minimize the inevitable disruption
   - Witness tests can take considerable time to complete
   - Track the performance of each machine using all available metrics by control chart
   - In-process monitoring may provide early warning of changes in machine performance
4. Emphasize the importance of inspection for every part
   - Not just NDE, but visual inspection of as-built conditions
   - Watch for changes in part appearance – colors, support structure issues, witness lines/shifts
5. Consider systemic implications for all non-conformances

Fracture Control Framework for AM Parts

- Fracture control is reliant on understanding the design, analysis, testing, inspection and tracking of hardware.
  - The adaptation of state-of-the-art AM technologies introduces new and unique challenges
    - e.g. Multiple lasers and adaptive technologies
  - For AM applications the application of conventional NDE techniques is questionable
  - There is a need to produce alternate approaches through the adaptation of a Probabilistic Damage Tolerance Approach (PDTA)
    - Computational modeling for AM
    - Understanding the "Effects of defects"
    - In-situ monitoring and inspection

These items MUST work together, NOT separately

Conclusions

1. Certification rationale is most heavily rooted in the foundational controls
2. Part Planning must confirm the foundation produces a good part consistently
3. Part production follows a fixed process with statistical process controls
4. Going forward NASA must develop a Fracture Control Framework for AM Parts which includes the adaptation of a Probabilistic Damage Tolerance Approach (PDTA)
    - Computational modeling for AM
    - Understanding the “Effects of defects”
    - In-situ monitoring and inspection

Next talk

Comparison of NASA and ECSS Standards for Additive Manufacturing Qualification and Certification for Spaceflight Application

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1st International Conference on Advanced Manufacturing for Air, Space and Land Transportation, Virtual

March 7-10, 2022